Chemistry

Lecture 12 By: Syed Ali Shan

Gases

Outline:

- Properties of gases
- Gas laws
    - Boyle's law
    - Charles's law
- General gas equation (ideal gas equation)
- Kinetic molecular theory of gases

States of Matter

- Matter exists in four states i.e., solid, liquid, gas and plasma.
- The simplest form of matter is the gaseous state
- Most of matter around us is in the solid state.
- Most in universe is plasma (ionized mixture of ions + electrons + neutral atoms)
- Liquids are less common than solids, gases and plasmas.
- The reason is that the liquid state of any substance can exist only within a relatively narrow range of temperature and pressure

Gaseous State

- Gases don't have a definite volume
- They don't have a definite shape
- Low densities of gases as compared to those of liquids and solids
- Gases can diffuse and effuse
- Gases can be compressed by applying a pressure
- Gases can expand on heating or by increasing the available volume
- When sudden expansion of gases occurs cooling takes place, it is called Joule Thomson effect
- Molecules of gases are in a constant state of random motion, collide with walls of container and exert pressure
- The intermolecular forces in gases are very weak

Units of Pressure:

- The pressure of air that can support 760 mmHg column at sea level, is called one atmosphere
- It is the force exerted by 760mm or 76cm long column of mercury on an area of $1cm^2$ at 0°C
- 1mmHg = 1torr
- The S.I. unit of pressure is expressed in Nm^{-2}

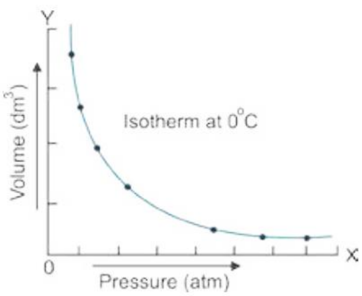
- One atmospheric pressure i.e. 760 torr is equal to 101325 Nm^{-2}
- 1pascal = 1 Nm^{-2}
- 760 torr = 101325Pa = 101.325 kilopascals
- 1 atm = 760 torr = 14.7 pounds $inch^{-2}$
- The unit millibar is commonly used by meteorologists

Gas Laws

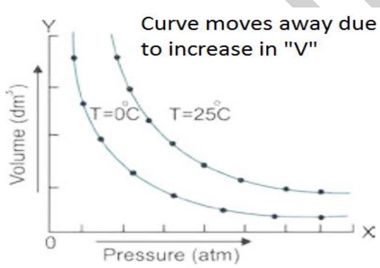
"The laws which give relationship between volume and prevailing conditions i.e. pressure, temperature and moles of ideal gases"

Boyle's Law:

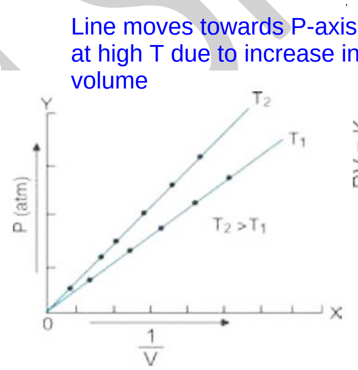
- The volume of a given mass of a gas at constant temperature is inversely proportional to the pressure applied to the gas
- $V \propto \frac{1}{P}$ (at constant T, n) ⋙ $V = \frac{k}{P}$ ⋙ PV = k ⋙ $P_1V_1 = P_2V_2$
- The product of pressure and volume of a fixed amount of a gas at constant temperature is a constant quantity

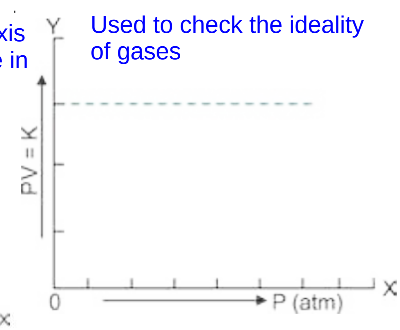


Isotherm of a gas at 0 °C.



Isothermes o f a gas at different temperatures.





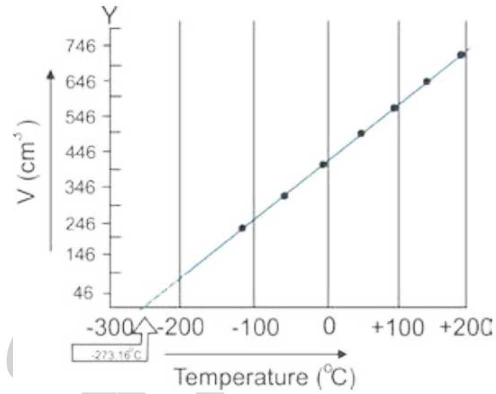
- SI unit of PV is **Nm**
- Non SI unit is **atm dm^3**
- k depends upon (i) T and (ii) Nature and amount of gas

Charles's Law:

- It is a quantitative relationship between temperature and volume of a gas
- Volume of the given mass of a gas is directly proportional to the absolute temperature when the pressure is kept constant
- $V \propto T$ (at constant P, n) ⋙ V = kT ⋙ $k = \frac{V}{T}$ ⋙ $\frac{V_1}{T_1} = \frac{V_2}{T_2}$
- The ratio of volume to temperature remains constant for same amount of gas at same pressure
- k depends upon (i) P and (ii) Nature and amount of gas
- Obeyed on Kelvin scale
- Volume becomes double with 273 k increase in T

Absolute Zero

- Hypothetical temperature at which volume becomes zero (molecular motion ceases) is called absolute zero with value **0 k (-273.16^{0}C)**
- All the gases liquefy before reaching this temperature
- It is unattainable temperature
- Lowest temperature achieved is 10^{-5} k



Quantitative definition of Charles's law:

At constant P, the volume of given mass of gas increases or decreases

by 1/273 of its original volume (at 0^{0}C) for every 1^{0}C rise or fall in T

Scales of Thermometry

- Centigrade/Celsius scale (^{0}C)
- Fahrenheit scale (^{0}F)
- Kelvin scale (K)

$$K = {}^0C + 273.16$$
$${}^0C = 5/9\,({}^0F - 32)$$

Avogadro's Law:

- Equal volumes of all the ideal gases at the same temperature and pressure contain equal number of molecules
- Volume does not depend upon amount (distance b/w molecules is 300 times than their diameter), only depends on number of molecules (moles)
- $V \propto n$ (at constant P, T) ⋙ V = kn ⋙ $k = \frac{V}{n}$ ⋙ $\frac{V_1}{n_1} = \frac{V_2}{n_2}$
- k depends upon (i) P and (ii) T

General Gas Equation (Ideal Gas Equation)

- PV = nRT (By combining all three gas laws)
- **Gas laws from ideal gas equation;**
- $V = \frac{nRT}{P}$ (n, T constant) ⋙ Boyle's law
- $V = \frac{nRT}{P}$ (n, P constant) ⋙ Charles's law
- $V = \frac{nRT}{P}$ (P, T constant) ⋙ Avogadro's law
- For one mole; ⋙ PV = RT
- $\frac{P_1V_1}{T_1} = \frac{P_2V_2}{T_2}$

Application of ideal gas

- Molecular mass of gas
- Density of gas

- $M = \frac{mRT}{PV}$ $d = \frac{PM}{RT}$ ⋙ **$d \propto P$, $d \propto M$, $d \propto 1/T$**

Units of R:

- It is work done per Kelvin per mole OR amount of energy absorbed by 1 mole with 1 Kelvin increase in temperature
- **Non-SI Unit;** ⋙ $R = 0.0821\ atmdm^3mol^{-1}k^{-1}$, $R = 62.4\ torrdm^3mol^{-1}k^{-1}$, $R = 62.4\ mmHgdm^3mol^{-1}k^{-1}$, $R = 62400\ torrcm^3mol^{-1}k^{-1}$
- **SI Unit;** ⋙ $R = 8.314\ Nmmol^{-1}k^{-1}$, $R = 8.314\ Jmol^{-1}k^{-1}$, $R = 1.98\ calmol^{-1}k^{-1}$

Kinetic Molecular Theory of Gases:

- Proposed by Bernoulli;
- Postulates

i. Each gas consists of small particles called molecules
ii. Molecules are in random motion
iii. Collide with walls (elastic collision) and exert pressure
iv. Large empty space
v. No force of attraction
vi. Negligible volume of gas molecules

Faulty postulates

vii. Negligible effect of gravity on motion
viii. Average kinetic energy is directly proportional to absolute temperature ($E_k = \frac{3R}{2N_A} \times T$)

- Kinetic gas equation given by Clausius $PV = \frac{1}{3} mN\bar{c}^2$
- N = number of molecules of gas in the vessel
- $\bar{c}^2$ = mean square velocity
- Maxwell's distribution of velocities; $\overline{c^2} = \frac{c_1^2 + c_2^2 + c_3^2 + \ldots\ldots}{n_1 + n_2 + n_3 + \ldots\ldots}$
- Root mean square velocity is; $C_{rms} = \sqrt{\frac{3RT}{M}}$

Motion of Gas particles

- Translational motion
- Rotational motion
- Vibrational motion
  - A mono-atomic molecule will show only translational motion while diatomic or polyatomic molecule will show all three motions
  - Molecular motion is directly related to temperature

Translational motion: This motion occurs in all directions and energy associated with it is called kinetic translational energy. The entire molecules move from place to place

Rotational motion: This motion occurs due to net angular momentum about their centre of gravity and the energy associated is called kinetic rotational energy. Molecule spins like a propeller

Vibrational motion: This motion occurs due to oscillations and energy associated is called kinetic vibrational energy. Molecules move back and forth about the same fixed location

Ideal and Non-ideal Behavior of Gases:

Ideal Gases	Non-ideal Gases
Obey gas laws at conditions of T and P	Do not obey gas laws at all conditions of T and P
Follow all postulates of KMT	It is due to two faulty postulates of KMT
Cannot be liquefied	Can be liquefied
At low T and high P(forces are dominant and volume isn't negligible), gases behave non-ideal	
Polar gases show more non ideal behavior than non polar due to strong forces	
Among the non polar gases, the gases with large molar mass are more non-ideal	
PV/RT = compressibility factor	
P V/RT greater or less than 1 means non-ideal gas	
PV/RT = 1 means ideal gas	

Van der Waals Equation:

- Applicable to non-ideal (real) gases
- Volume occupied by 1 mole of gas in highly compressed state is called effective/excluded volume [b, (SI-unit is m^3mol^{-1})(Non=SI is dm^3mol^{-1})]
- $b = 4\ V_m$ (V_m = actual volume in uncompressed form)
- $(P_{obs.} + \frac{an^2}{V^2})\ (V_{vessel} - nb) = nRT$
- "a" is coefficient of attraction
- SI unit of "a" = Nm^4mol^{-2} Non-SI unit of "a" = $atmdm^6mol^{-2}$
- If "a" and "b" are large → gas is non-ideal
- If "a" and "b" are small → gas is near to ideal/resemble ideal
- If "a" and "b" are zero → gas is ideal